CONTROL OF THE SUGAR-BEET NEMATODE

HARRY B. SHAW

Pathological Inspector, Federal Horticultural Board; formerly Assistant Pathologist
Office of Sugar-Plant Investigations

IMPERIAL BUREAU
28 JUN. 1921
OF MYCOLOGY

FARMERS' BULLETIN 772

UNITED STATES DEPARTMENT OF AGRICULTURE

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. December, 1916

PUBLICATIONS OF THE UNITED STATES DEPARTMENT OF AGRICULTURE RELATING TO DISEASES OF SUGAR BEETS AND SOME OTHER CROPS.

AVAILABLE FOR FREE DISTRIBUTION BY THE DEPARTMENT.

Sugar-Beet Growing under Irrigation. (Farmers' Bulletin 567.)
Sugar-Beet Growing under Humid Conditions. (Farmers' Bulletin 568.)
Leaf-Spot, a Disease of the Sugar Beet. (Farmers' Bulletin 618.)
Cotton Wilt and Root-Knot. (Farmers' Bulletin 625.)
The Control of Root-Knot. (Farmers' Bulletin 648.)
Grasshoppers and Their Control on Sugar Beets and Truck Crops. (Farmers' Bulletin 691.)
Wireworms Destructive to Cereal and Forage Crops. (Farmers' Bulletin 725.)
Cutworms and Their Control in Corn and Other Cereal Crops. (Farmers' Bulletin 739.)
Thrips as Pollinators of Beet Flowers. (Department Bulletin 104.)
Loss in Tonnage of Sugar Beets by Drying. (Department Bulletin 199.)
Field Studies of the Crown-Gall of Sugar Beets. (Department Bulletin 203.)
Nematodes and Their Relationships. (Separate 652, from Yearbook 1914.)

FOR SALE BY THE SUPERINTENDENT OF DOCUMENTS, GOVERNMENT PRINTING OFFICE, WASHINGTON, D. C.

The Sugar Beet, Culture, Seed Development, Manufacture, and Statistics. (Farmers' Bulletin 52.) Price, 5 cents.
Sugar Beets: Preventable Losses in Culture. (Department Bulletin 238.) Price, 10 cents.
The Curly-Top of Beets. (Bureau of Plant Industry Bulletin 181.) Price, 15 cents.
Root-Knot and Its Control. (Bureau of Plant Industry Bulletin 217.) Price, 15 cents.
The American Beet-Sugar Industry in 1910 and 1911. (Bureau of Plant Industry Bulletin 260.) Price, 25 cents.
The Nematode Gallworm on Potatoes and Other Crop Plants in Nevada. (Bureau of Plant Industry Circular 91.) Price, 5 cents.

CONTROL OF THE SUGAR-BEET NEMATODE.[1]

CONTENTS.

	Page.
Description and life history of the sugar-beet nematode	3
The beet nematode in Europe	6
The beet nematode in the United States	7
Effects of beet-nematode attacks	7
Differences between the beet nematode and the root-knot nematode	10
Conditions favorable to the beet nematode	11
Methods of spreading the pest	12
Plants subject to attack by beet nematodes	13
Plants not subject to attack	14
Ineffective methods of combating the nematode	15
How to fight the beet nematode	15
Crops available for rotation on infested land	17
Preventing the further introduction of the beet nematode	18
Breeding or selecting resistant beets	18
Summary	18

AMONG the serious pests that have done much injury in European countries, one of the worst is the sugar-beet nematode,[2] or eelworm, as it is more popularly called, on account of its resemblance to an eel. This eelworm has been found in the principal beet districts of Germany, Austria-Hungary, western Russia, Holland, Belgium, France, Denmark, and Sweden, as well as the Azores, in all of which regions it has caused immense losses.

Unfortunately, the sugar-beet nematode already has gained entrance into the United States. For this reason information should be available at once to aid in its control and to check its further introduction and spread.

DESCRIPTION AND LIFE HISTORY OF THE SUGAR-BEET NEMATODE.

There are numerous kinds of eelworms; many of them are very injurious; some infest animals and others attack plants.

The sugar-beet eelworm is known in six forms, or stages: (1) The egg, (2) the first larval stage, (3) the second larval stage, (4) the adult male, (5) the adult female, and (6) the so-called brown cyst, or preservation form. (Fig. 1.)

The egg.—The female can produce from 350 to 400 microscopic, colorless, oval or kidney-shaped eggs. These are so small that 350 of them placed end to end would extend only 1 inch; their width is about half their length.

The larval stages.—The young eelworm, or larva as it is called, that hatches from each of these eggs is an exceedingly fine, thread-like, active, colorless creature. It tapers at each end and possesses

[1] Scientific name, *Heterodera schachtii* Schmidt.

[2] Nematode means threadworm and is the name in use in scientific circles for the numerous species of minute eelworms.

mouth parts armed with a spear, which the worm can dart back and forth rapidly and continuously. This is known as the first larval

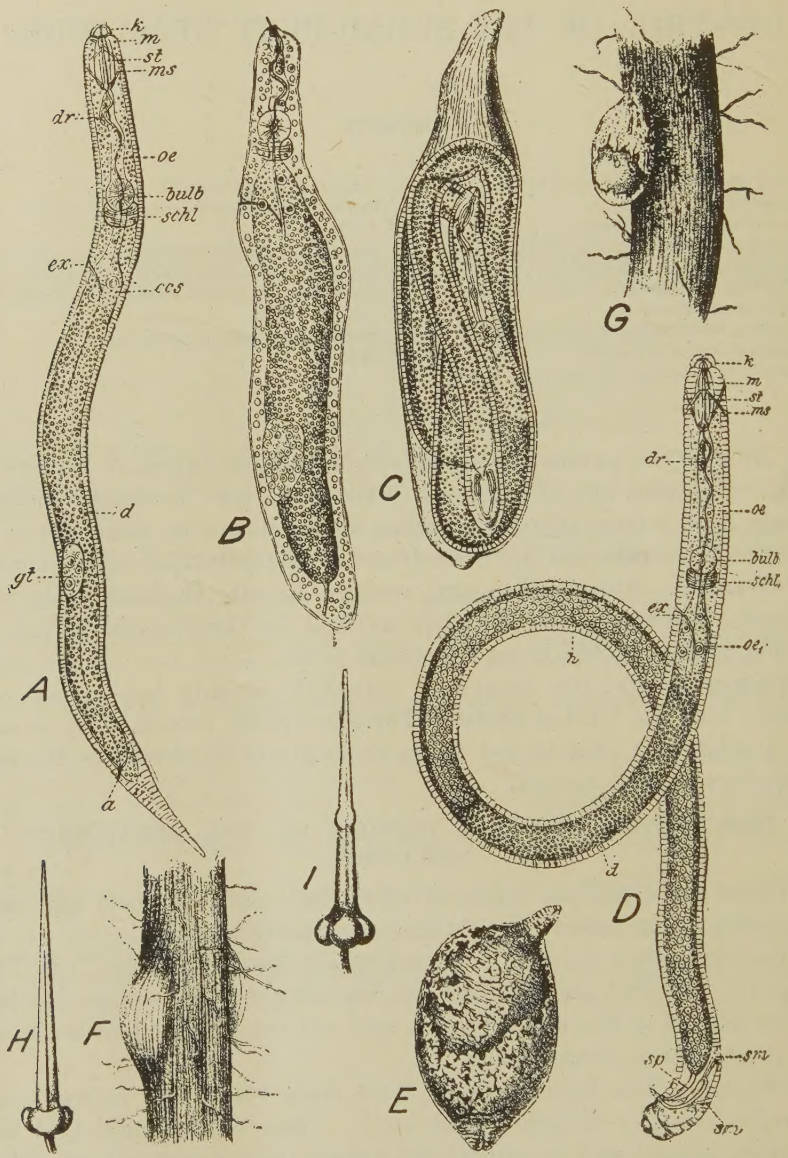

FIG. 1.—The sugar-beet nematode (*Heterodera schachtii* Schmidt): *A*, The first-stage larva, ×200; *B*, the second-stage larva; *C*, the second-stage larva, showing the young male adult beneath the larval skin; *D*, the adult male, ×330; *E*, the adult female, ×30; *F*, a rootlet with swellings caused by larvæ embedded in the tissues, ×15; *G*, the body of an adult female protruding from a beet rootlet, ×15; *H*, the larval spear, ×1,440; *I*, the spear of the adult, ×1,440. (After drawings by Strubell.)

stage. (Fig 1, *A*.) It averages only one-seventieth of an inch in length; its thickness is about one-twentieth of its length. It is so

active that it can travel as far as 10 feet, or about 8,400 times its own length, in two weeks, in search of suitable food plants. On finding a rootlet, it forces its way into the outer tissues with its strong, rapidly moving spear. It then feeds on the plant juices. Up to this time the sex of the larva can not be distinguished.

Shortly after entering the tissues of the rootlet it undergoes certain changes, molts, and assumes the flask form, or second larval stage. (Fig. 1, *B*.) Finally, it molts again, to become an adult male or female. The sex can be distinguished some little time before the second molting. (Fig. 1, *C*.)

The adult male.—If the second-stage larva proves to be a male, on emerging from the larval skin he will at once proceed to break his way from the rootlet by means of the stronger spear with which he is now equipped. On escaping from the rootlet he seeks a female, and after fertilizing her he dies. The adult male is considerably larger than the larva, being about one twenty-fifth of an inch long and about one-thirtieth as thick. (Fig. 1, *D*.)

The adult female.—Should the second-stage larva chance to be a female, she rapidly undergoes changes in form; her body becomes enlarged, almost lemon shaped, until it bursts the outer portion of the rootlet in which she was embedded and protrudes from it. (Fig. 1, *G*). She remains thus after being fertilized, with only her head parts attached to the rootlet, until she is fully matured and the eggs are ready to hatch. Her length is about one-twentieth of an inch. Her body is of a pale yellowish white tint. When fully matured, she dies and drops from the rootlet. (Fig. 1, *E*.) If conditions then are favorable the eggs begin to hatch and the young eelworms travel in search of suitable roots upon which to feed.

From the egg of one generation to that of another the time occupied is only four or five weeks. As many as seven generations may come into existence in a single season.

The brown-cyst stage.—The term "brown cyst" was applied by the discoverer of the preservation form of the sugar-beet eelworm because it so well describes its appearance. A cyst is simply a small bladderlike bag, or sac.

A knowledge of certain facts concerning the brown cyst is important, because it may suggest means of preventing the further introduction and spread of the pest, as well as indicate methods of controlling it.

It was formerly believed that no further change took place in the development of the female after she had reached maturity and eggs had been formed within her lemon-shaped body. It was thought that all adult females then died and, if the weather remained sufficiently mild, the eggs hatched and the young eelworms escaped from the dead body to infest other plants, and that if severe weather prevailed

when the female died, most of the eggs and young were destroyed. However, it was discovered that on the approach of cold weather, or when other conditions arise that are unfavorable to the female nematodes, many of them undergo further changes. The coverings of the lemon-shaped body gradually become thicker and tougher and assume a dark-brown color. This thickening and toughening is a protective process. When this stage has been reached the female no longer shows any sign of life; her body has become a protective sac, within which the eggs are protected and preserved from outside injurious influences. The brown cysts remain loose in the soil, the rootlets from which they fell having rotted.

The brown cyst is the preservation form of the sugar-beet eelworm. It remains unchanged throughout the winter, protecting the eggs until returning warm weather causes them to hatch. In many instances it was found that the eggs contained in the brown cyst hatch out a few at a time during a period that may extend over several years until nothing remains but the empty, tattered remnants of the cyst. This accounts for the fact that sugar-beet eelworms have been known to persist in ground from which all food plants have been carefully kept for several years.

Although the cold of winter appears to be unable to injure eggs protected by the brown cyst, they may be injured by undue heat; in fact, the entire contents of the cyst can be destroyed by an exposure for one minute to a dry heat of 145° F. A much lower temperature will kill the nematode in any other stage of its existence.

THE BEET NEMATODE IN EUROPE.

Rather early in the history of the beet-sugar industry of Europe it was seen that beets in certain fields or portions of fields became very sickly in appearance and attained only a small size. This condition became more and more general, until it had reached such alarming proportions as to cause the closing of many beet-sugar factories through the decrease in the yield of beets in the affected areas. It was long believed that an exhaustion of some of the mineral plant foods in the soil occasioned this behavior of the beets, especially since fields in which beets had been grown for many years in succession were most affected. On this account the Germans named the trouble "beat weariness" of the soil—a name still extensively used in Germany, although it is now well known that the trouble is caused by the attacks of this microscopic eelworm.

As already mentioned, the beet nematode is very widely spread in Europe, being found in practically every European country where sugar beets are grown. It is not certain whether this pest is a native of Europe; probably it was carried into Europe on plants imported from the Tropics more than a century ago.

THE BEET NEMATODE IN THE UNITED STATES.

It should be realized that the sugar-beet eelworm already has been introduced into the United States, that it has even become well established in several of the older beet districts in the West, that where it has been established it is locally as destructive as anywhere in Europe, and that as yet practically no steps have been taken to check or eradicate it or to prevent its further introduction and spread. Therefore, to save the beet-sugar industry of the United States from bitter experiences and enormous losses, like those suffered by European beet growers, no time should be lost in putting into operation suitable preventive measures.

In view of the fact that all the forms of this nematode, except the brown cyst, are sensitive to drying, it seems very probable that the pest has largely been introduced in the preservation form, or brown cyst. At harvest, the cut stems of ripe beet seed frequently come in contact with the ground, and particles of soil cling to them. If this soil were infested with brown cysts it seems probable that some of them would find their way into the sacks of beet seed and be carried to any country importing the seed. Even a small number of brown cysts thus distributed every year in any given locality would be sufficient to establish the pest there, especially where successive crops of sugar beets are grown year after year in the same fields. It may also have been introduced in any stage of development in moist soil clinging to the roots of imported plants and potatoes.

To judge from the extent to which the beet eelworm had become established in some of the oldest beet districts of the West in 1907, when it was first recognized there, it must have been introduced a number of years earlier. At first its spread in these localities was rather slow. A survey made in 1912 showed the nematode to be steadily spreading in regions originally infested, that it had been introduced into new areas widely separated from the districts originally found infested, but that there were still many beet districts where it had not been discovered.

EFFECTS OF BEET-NEMATODE ATTACKS.

EFFECT ON THE ROOTS OF BEETS.

The active young beet eelworms are in some way able to find the roots of sugar beets and other plants upon which they feed. Generally they attack fine rootlets about one twenty-fifth of an inch in diameter. With its strong spear (fig. 1, *H*) the larva is able to pierce its way into the tissue of a rootlet until it is entirely embedded. In the rootlets the eelworms feed on the plant juices, thus partly exhausting the plant. In addition, their presence and activities seem to cause an irritation in the rootlets and bring about the destruction of some of the cells and the plugging of the conducting

tubes. Finally, the infested rootlets are unable to convey water and mineral solutions from the soil to the beets. The rootlets then die. In an effort to overcome this trouble the beet repeatedly puts forth new rootlets. At length a characteristic dense mass of rootlets is developed. In Europe this condition has earned the names "hunger roots," "bearded roots," "hairy-root," etc. (Fig. 2.) When the plant is badly infested, the beet itself is stunted and looks very much like the root of a celery plant. It is sometimes called "celery-root" on that account. This condition also closely resembles that of beets severely attacked by curly-top and known in this country as "whiskered beets." (Fig. 3.)

FIG. 2.—A sugar beet infested with beet nematodes. The white bodies of female nematodes can be seen clinging to the rootlets.

FIG. 3.—A sugar beet affected with curly-top, showing the characteristic dense mass of rootlets.

A close examination of such beet roots will generally reveal the presence of numerous yellowish white beadlike objects clinging to the rootlets. (See fig. 2.) These are the protruding bodies of female nematodes. This form and the brown cyst are the only stages of the beet nematode that are visible to the naked eye. Occasionally small swellings may be found on infested rootlets (fig. 1, *F*). They occur chiefly where young eelworms have been at work only a short time. When many of these exist close together they may somewhat resemble the galls caused by the nearly related root-knot nematode, but they are later absorbed or buried in the continued growth of the rootlets.

Eelworms can not be found on beet rootlets during the last stage of the trouble; that is, where the beets are dead or dying in badly infested fields. On the other hand, they may be found on beets that have made some recovery or shown resistance.

EFFECT ON THE FOLIAGE.

Naturally, such interference with the activities of the rootlets will seriously affect all portions of infested plants; consequently, the leaves show signs of the nematode attacks, although these nematodes never attack any part of the plant above ground.

Toward the end of July or early in August spots may be noted in beet fields where the foliage has become lighter in tint than that

FIG. 4.—A sugar-beet field, showing a sharply defined area where many beets have been destroyed by nematodes infesting the roots. (Photographed by L. P. Byars.)

of healthy beets; the leaves of the affected plants droop until they lie prone upon the ground, and they do not recover during the night. The outer leaves become yellowish, spotted, and generally discolored; then they wilt and die. The inner leaves fail to reach their normal size, and if the plant is badly infested, they also die. Occasionally the crown of infested beets becomes blackened with rot. Starting at the crown, the rot may penetrate the root, causing it to become brown and limp. This rot is not caused by the eelworm itself, but by bacteria or fungi that are enabled to attack the sick beet. When not severely attacked, the beet may survive until harvest. In such a case new heart leaves are developed, which, however, do not attain the size of healthy beet leaves, are often curled and misshapen, and assume a dark-green color.

At first the eelworm may infest only small areas; these are sharply defined by the gaps left by the destruction of the badly infested beets. (Fig. 4.) Often whole fields are infested.

EFFECT ON THE YIELD AND SUGAR CONTENT OF BEETS.

The average weight of foliage of sugar beets infested with beet nematodes may fall as low as one-fifth that of healthy beets; the average root weight suffers correspondingly. A representative experiment showed an average of 14.9 per cent of sugar in healthy beets, 11.35 per cent in beets moderately infested with nematodes, and only 8.4 per cent in badly infested beets. Both leaves and roots of healthy beets are found to contain a much higher percentage of proteids and other nitrogenous compounds, as well as an enormously increased percentage of dry ash, than the corresponding parts of nematode-infested beets. This also shows how seriously the functions of the beet are interfered with.

DIFFERENCES BETWEEN THE BEET NEMATODE AND THE ROOT-KNOT NEMATODE.

The sugar-beet nematode is related to and rather closely resembles the root-knot nematode.[1] To assist in distinguishing them the following differences are pointed out:

THE BEET NEMATODE.	THE ROOT-KNOT NEMATODE.
Produces no galls on beets.	Produces galls on beets (fig. 5).
Body of female remains outside the beet, only the head parts being embedded.	Entire body of female usually buried in root tissue, though portions of hind part of body may occasionally be found outside the roots.
Female usually lemon shaped, dull white, and flaky.	Female pear shaped or flask shaped, glistening, and pearly white. (Fig. 1, *E*, and fig. 6.)
Some eggs deposited outside the body of the female, but most of them develop within the body.	All but last few eggs deposited outside the body of the female.
Spear of larva and adult male longer and stouter than that of the root-knot nematode.	Spear of larva and adult male shorter and weaker than that of the beet nematode.
Possesses a brown-cyst stage.	Has no brown-cyst stage.
Larvæ can not withstand the cold of winter.	Larvæ can withstand the winter.
Can thrive in heavy soils.	Can thrive only in the lighter, sandy soils.
Causes "hairy-root."	Does not cause "hairy-root."
Greatly decreases sugar content of infested beets.	Slightly decreases sugar content of infested beets.

[1] Scientific name of the root-knot nematode, *Heterodera radicicola*.

CONDITIONS FAVORABLE TO THE BEET NEMATODE.

SOIL.

Cultural conditions in general favor the spread and perpetuation of the beet nematode, but it is sufficiently robust to thrive in almost any kind of soil, light or heavy. In this respect it is unlike the root-knot nematode, which can thrive only in the lighter, sandy soils. Doubtless this is due to the fact that the beet eelworm possesses a much stronger spear than the root-knot nematode.

FIG. 5.—A sugar beet affected with root-knot. In certain sections of the Southwest the growing of sugar beets has been prevented by this disease.

WEEDS AND OTHER PLANTS.

The sugar-beet eelworm can live on the roots of many different kinds of plants. These include some of the commonest weeds, as well as cultivated plants. Weeds springing up after harvest, along roadsides, and on the margins of fields and irrigation ditches are fine hold-over places for this pest.

TEMPERATURE.

Although the eggs and larvæ are killed by slight frosts, the brown cyst can withstand the rigors of winter and preserve the eggs it contains. Probably some larvæ seek the deeper soil on the approach of winter and others gain entrance to root tissues, where they survive until the following spring. The summer temperature of the soil is highly favorable to the rapid development of this eelworm. All forms of the sugar-beet eelworm except the brown cyst are destroyed by a temperature of 95° F., whereas a temperature of not less than 145° F. is necessary to make certain the destruction of eggs protected within the brown cyst. In many States the cold of winter is severe enough to penetrate sufficiently deep to destroy all except those protected within the brown cysts. In localities having high summer temperatures the nematode is not destroyed by the

heat, because it is protected by the moist soil, which at a depth of a few inches never attains the high temperature of the air.

MOISTURE.

The degree of moisture usually retained in cultivated soils is very favorable to the beet eelworm.

SUCCESSIVE SUSCEPTIBLE CROPS.

The repeated growing of sugar beets and other crops subject to attack by beet eelworms is most favorable to the continuance and increase of the pest.

PROLIFIC CHARACTER.

The pest is very prolific. It may bring forth five to seven generations during a growing season. It has been calculated that if each female brought forth only 100 young, in six generations it would be possible for one pair to produce 31,887,755,100 individuals, or the astounding number of 22,781,000,000,000 if each female produced the entirely possible number of 300 young.[1]

ABSENCE OF ENEMIES.

The sugar-beet eelworm is not known to have any insect or other natural enemy, except, perhaps, some species of nematodes that devour their kind, and it is protected to a large extent from climatic dangers by the soil.

METHODS OF SPREADING THE PEST.

MOVEMENT BY ITS OWN POWER.

The sugar-beet nematode is able to extend its ravages greatly by its own movements. Under favorable conditions the larvæ can travel about 10 feet in one generation. Thus in the five to seven possible generations they may travel from 50 to 75 feet. The distance traveled would depend largely on the proximity of suitable host plants, the character of the soil, and the duration of warm weather. As the weather becomes cooler the movements of the nematode become more and more sluggish.

OTHER MEANS OF TRANSPORTATION.

When they have once been introduced into a beet district, it is an easy matter to spread the eelworms from one field to another; indeed, it is difficult to avoid doing so. Soil infested with nematodes at any stage of development may be carried from one place to another on the hoofs of horses and other live stock, the wheels of wagons and other vehicles and implements, the shoes of persons, and especially

[1] Calculated by the Austrian investigators Vanha and Stoklasa.

the implements used in the fields. Heavy rains and irrigation water are capable of carrying the pest long distances, to infest more land. The soil left in wagons in which infested beets have been carried may be scattered broadcast over land not previously infested. The water in which beets have been washed at the sugar factory and the mud from the factory settling pond, as well as trash thrown from the factory, may be and often are prolific sources of reinfestation and wide distribution. Thus, the pest may be spread in an increasingly rapid manner after being established in a district.

FIG. 6.—A female of the gallworm (*Heterodera radicicola*), magnified 85 diameters: *a*, Mouth; *b*, spherical sucking bulb; *c*, *c*, ovaries, as seen through the body wall; *d*, anus; *e*, small white spots, showing approximately the natural size of these worms. During the egg-laying period they are usually a glistening white and can be readily seen with the unaided eye by carefully breaking open an infested gall. (After N. A. Cobb.)

It was discovered in Europe that one of the most serious methods of spreading the pest was by using as fertilizers waste water from the beet washers and mud from the settling pond. It was found that if the water of the settling pond were made alkaline to the extent of 0.031 per cent with quicklime, all the eelworms contained in such water would be destroyed within 40 days. However, it is doubtful whether such a treatment is practicable. On no account should eelworm-infested factory waste water, slime, or trash be applied to cultivated land; nor should composts mixed with infested soil be applied to clean land until the eelworms have been destroyed by the addition of a considerable percentage of fresh lime.

The beet nematode does not pass through the intestines of sheep alive, but it is not yet known whether this is true of other farm animals. Therefore, it is advisable that all beet tops and other parts of sugar beets and other plants infested with nematodes be fed to sheep alone until it has been definitely determined whether or not the pest in any of its forms can pass through other animals and remain alive.

PLANTS SUBJECT TO ATTACK BY BEET NEMATODES.

The sugar-beet nematode is known to attack numerous kinds of plants. Although some kinds of crops susceptible to the sugar-beet nematode do not show the effects of the attacks of this eelworm, such plants should not form a part of the rotation series on nematode-infested ground, as they would help to increase the number of beet nematodes in the soil.

The plants named in the following list are known to be subject to the attacks of the beet nematode:

Alfalfa.
Allseed.
Barley.
Bean, dwarf pea.
Bean, Lima.
Beets, Garden.
Beets, sugar.
Cabbage.
Cabbage, Chinese.
Cauliflower.
Celery.
Clover, crimson.
Clover, white.
Corn.
Cress.
Dandelion.
Foxtail, green.
Hemp.
Hops.
Kale.
Kohl-rabi.
Lentils.
Lupine, yellow.
Meadow grass, annual.
Meadow oat-grass, tall.
Mustard.
Oats.
Parsnip.
Pea, garden.
Pea, sweet.
Pink.
Potato.
Radish.
Rape.
Rutabaga.
Rye.
Sorghum.
Spinach.
Sunflower.
Timothy.
Turnip.
Vetch.
Wheat.

According to the degree of certainty with which these plants are subject to attack, they may be grouped as follows:

(1) Those especially and regularly subject to attack. These include every kind of beet; also cabbage, cauliflower, Brussels sprouts, rape, white and black mustard, cress, and kohl-rabi.

(2) Those upon which nematodes only occasionally appear. Oats are the chief example.

(3) Plants which are attacked by scattered individuals or by colonies of nematodes. Such are the legumes, the clovers, barley, corn, rye, wheat, Lima bean, and potato.

(4) Most of the common weeds.

PLANTS NOT SUBJECT TO ATTACK.

Although the list of plants not known to be subject to the attacks of the beet nematode is large, doubtless many of these supposedly immune plants will prove to be susceptible. Among those at present found in European countries to be free from or highly resistant to the attacks of this pest are the following:

Field crops.—Buckwheat, chicory, the clovers (except crimson and white), flax, the grasses (except tall meadow oat-grass), horse, bean, pea (Spanish, everlasting, and yellow flowered, but not the garden or field pea), spelt, tobacco.

Truck crops.—Artichoke, asparagus, carrot, chives, cucumber, gooseberry, horseberry, leek, lettuce, onion, oyster plant, parsley, pepper (red and cayenne), pumpkin, raspberry, shallot, strawberry.

Miscellaneous crops.—Almond, anise, apple, caraway, cherry (mahaleb), coriander, dill, hollyhock, marigold, marjoram, mint (curled), poppy, purslane, sage (white and scarlet), savory, thyme, violet (English).

The more important of these crop plants are arranged below in three groups, according to their relative economic importance:

Of importance.—Herd's grass (redtop), Rhode Island bent-grass, orchard grass, tall meadow grass, flax, tobacco, greengage plum (the *domestica* varieties), spelt.

Of less importance.—Onion, red or cayenne pepper, parsley, chicory, asparagus, cucumber, pumpkin, carrot, strawberry, Jerusalem artichoke, lettuce, oyster plant.

Of great or small importance, according to locality.—Indian millet, white sweet clover.

In Europe the potato is found to be but little subject to beet-nematode attack and is therefore generally included in the rotation series. This crop plant might be added to the third group. It has also been reported that in California barley, corn (maize), Lima beans, and wheat are so little susceptible to nematode attack as to be recommended for use in a rotation series.[1]

INEFFECTIVE METHODS OF COMBATING THE NEMATODE.

To save the beet grower of this country from useless efforts, mention will be made of some of the methods that have proved either useless or impracticable on a field scale or are too costly. The seed of some rapidly growing crop, such as rape, which is very attractive to this pest, was sown between the rows of beet seed. This so-called trap crop soon sprouted and attracted the eelworms to its roots. At a proper time the trap crop was plowed up, exposing the roots to sunshine and thus killing the nematodes. This method proved too uncertain.

Various chemicals, such as carbon disulphid, gas water, gas lime, quicklime, and calcium carbid, have been applied locally. Although some of these chemicals were effective on a small scale, all were abandoned because they were either too costly or not applicable under field conditions.

Heavy applications of commercial fertilizers have been tried, but these were never worth the extra cost, nor did they lessen the number of eelworms.

Live steam may be used on very small plats, but it is useless on a large scale.

HOW TO FIGHT THE BEET NEMATODE.

It can not be too strongly impressed on the grower that the beet nematode is a truly formidable pest. As with many other evils, an ounce of prevention is worth a pound of cure. After a field has become infested with beet nematodes it is not easy to get rid of them.

SURVEY OF SUSPECTED FIELDS.

It is first necessary to learn what fields or portions of fields are infested. To do this, a survey of suspected beet fields should be made soon after the hot season has set in; this is probably about the middle of July in most beet districts. At this time the signs of nematode attack—the wilting and yellowing of the leaves—may be seen.

[1] Rittue, E. C., Assistant in Sugar-Plant Investigations, Bureau of Plant Industry.

A map or plan should be made of each infested field; upon this map all infested areas should be carefully marked, so that the grower may watch the marked spots from year to year.

LOCAL MEASURES.

After the discovery of the pest it is important that no time be lost in checking or destroying it. Local measures may then be sufficient. We will suppose that one of the sharply defined infested areas has been found in a field of beets. The beets remaining in this spot and those for several feet around it should be pulled. As many of their rootlets as possible should also be removed from this place. The pulled beets and roots should next be destroyed by covering them with quicklime, though if they can be carried away without scattering the soil that clings to the roots they may be fed to sheep. A narrow trench, about a foot deep, should be dug around the spot from which the beets have been pulled. Unslaked lime must then be plentifully scattered in the trench, and the area inclosed by the trench must also be heavily spread with lime, which must be thoroughly mixed with the soil by digging the infested area at least a foot deep. This mixing must be repeated frequently during the hot weather, both to bring the lime in contact with the eelworms and to dry them out by exposing more and more of them to the air and sunshine, as well as to destroy weeds. This is the cheapest, most efficacious, and practical method for small areas.

FIELD METHODS.

Rotation with immune crops is the only method of checking this pest known to be effective and practicable when large areas or entire fields have become infested.

Disease and pest control by means of crop rotation is based on the fact that certain diseases and pests can thrive on and cause injury to particular kinds of plants, but not to others. To change the crops in a proper manner will deprive the disease or pest of the kind of plant it can thrive upon, and thus cause that disease or pest to become less severe or to disappear.

In planning a crop rotation for the control of the beet nematode the first consideration should be to make up the rotation series with crops not subject to attack by the beet nematode. However, it is desirable to keep other essentials of a good crop rotation in view at the same time. It should be the endeavor to arrange the rotation so as to leave each field in a better state of cultivation, as well as to keep in check pests and diseases to which each crop of the series may be subject.

While no definite rotation series is offered, because such a rotation must be adapted to each locality, even to each farm and field, cer-

tain broad principles should be applied in all profitable crop rotations. They should contain at least one leguminous crop, such as the clovers, beans, or peas. Such a green crop should be plowed under to furnish humus. Fortunately, it is possible to select leguminous crops not subject to attacks of the beet nematode. In this rotation care should be taken to avoid any crop besides beets that is subject to the attacks of these nematodes. This rotation series should be planned to cover not less than four or five years, which period has been found in European countries to be fairly satisfactory.

On account of the brown-cyst or preservation form of the beet nematode it would be safer to extend the rotation period to six years; then even the eggs protected by the brown cyst would all hatch out and succumb during such a period.

During the entire course of the rotation series very thorough culture should be practiced to keep down weeds; otherwise the use of immune crops will be of little avail. Weeds springing up after harvest along roadsides, on the margins of fields, and on the banks of irrigation ditches should be kept down or they will furnish hold-over places for the nematodes.

If the land is not badly infested, much benefit would follow a 4-year rotation.

CROPS AVAILABLE FOR ROTATION ON INFESTED LAND.

To assist the beet grower to plan a rotation series with crops immune to the beet nematode, the following schedule is offered for various parts of the United States where sugar beets are grown; since the beet zone of this country includes many States and different climatic conditions, several groups of States are dealt with.

(1) California and Arizona.

(2) Oregon and Washington.

(3) Utah, Montana, Nevada, Colorado, Kansas, and South Dakota.

(4) Nebraska, Wisconsin, Indiana, Michigan, Ohio, New York, and West Virginia.

The following nonsusceptible crops are suitable for these groups:

Group 1.—Cowpeas, soy beans, sweet clover, rye, the millets, tomatoes, asparagus, lettuce, cantaloupes, strawberries, barley,[1] corn,[1] Lima beans,[1] wheat.[1]

Group 2.—Cowpeas, soy beans, sweet clover, rye, the millets, truck crops (such as lettuce and asparagus, but not celery), barley,[1] wheat.[1]

Group 3.—In addition to the crops mentioned in group 2, cantaloupes, cucumbers, and potatoes.[1]

Group 4.—Clover, cowpeas, sweet clover, soy beans, rye, the millets, tobacco, flax, peppermint, cucumbers, strawberries, melons, lettuce, asparagus, some other truck crops, the grasses with the exception of tall oat-grass, barley,[1] corn,[1] Lima beans,[1] potatoes, and wheat.[1]

[1] Occasionally slightly infested with beet nematodes, but may be used in a rotation series.

PREVENTING THE FURTHER INTRODUCTION OF THE BEET NEMATODE.

Unfortunately, the means by which the beet nematode has been and perhaps still is being introduced into the United States have not been definitely established. This question is being studied by the United States Department of Agriculture.

It is possible that living nematodes in every stage of development have been brought in from European countries in the moist soil adhering to the roots of nursery stock and potatoes. The pest could be introduced in the brown-cyst stage among imported beet seeds, though it has not yet been proved that they are so introduced. The other stages of the beet nematode could not exist for any considerable time among dry beet seeds, although other destructive species of eelworms can and do come into this country alive among beet seeds and in the small clods of soil generally found in sacks of imported beet seed.

Should it be found that the pest is introduced in the soil about the roots of imported plants, its continued introduction by this means could be prevented only by requiring the fumigation of all such plants by the new vacuum process or by forbidding the importation of plants whose roots carry soil.

Should it be ascertained that the brown-cyst stage of the beet nematode is brought in with imported beet seeds, it will be practicable to destroy it without injury to the seeds. It has already been stated that the entire contents of the preservation form can be destroyed by exposure to a dry heat of 145° F. for as short a time as 1 minute. Experiments have shown that exposures of 5 to 10 minutes to dry heat as great as 149° to 158° F. not only fail to injure beet seed, but appreciably improve its germinability. Thus, a method is available to destroy beet eelworms imported with beet seed, should it be found that the pest is so introduced.

BREEDING OR SELECTING RESISTANT BEETS.

Experience with other plants indicates that it might be possible through breeding and selection to develop strains of sugar beets resistant or distasteful to the beet nematode. However, this is not a matter than can well be handled by the beet grower; it is a problem that could best be taken up by the United States Department of Agriculture, the State agricultural experiment stations in the beet zone, and other agencies interested in producing beet seed.

SUMMARY.

The sugar-beet nematode,[1] a species of eelworm closely related to the root-knot nematode,[2] has been for many years a serious pest of

[1] *Heterodera schachtii.* [2] *Heterodera radicicola.*

the sugar beet in European countries. The losses occasioned by this microscopic eelworm were at one time so great as to cause the closing of numerous European beet-sugar factories.

This nematode attacks the rootlets of beets and numerous other cultivated plants, as well as most of our common weeds. Its attacks on the rootlets of beets cause a clogging of their conducting vessels, and finally the destruction of the rootlets. In its efforts to recover, the beet repeatedly produces new rootlets, which at length form a dense mass characteristic of the trouble. Owing to the root injury the whole plant suffers; the leaves wilt without recovering during the night, turn yellow, and die. In severe cases the whole plant is destroyed, thus leaving sharply defined bare or partly denuded spots in the beet fields. Sometimes whole fields of sugar beets are almost entirely destroyed. The attacks of the pest cause a marked decrease in the sugar content of infested sugar beets.

This pest already has been introduced into the United States and has become established in several sugar-beet districts of the West, where its effects have been as injurious as in European countries. It may have been introduced with nursery stock, potatoes, or with beet seed.

After many years of experimentation it has been found that the only practicable method of controlling the pest on a large scale is by the rotation of crops not attacked by this nematode. A rotation of four or five years, including beets or other susceptible crops only once in the series, has been found in European countries to keep the pest fairly well under control, but owing to the fact that eggs may be preserved for a number of years in brown cysts, it would be safer to extend the rotation to six years.

Where only small areas of land are infested with beet nematodes it is possible to get rid of them by the liberal application of unslaked lime, which should be thoroughly mixed with the infested soil to a depth of at least a foot, the mixture of soil and lime being turned over frequently during the summer. These infested areas generally show themselves about the middle of July through the wilting and yellowing of the leaves. The wilted leaves do not recover during the night.

All forms of the beet nematode, including the resistant preservation form, the brown cyst, can be destroyed by a short exposure to a dry temperature of 145° F. Beet seed exposed to a dry temperature of 149° to 158° F. for 10 minutes is not injured by the treatment; on the other hand, its germinability is improved. Should it be established that the beet nematode is introduced with beet seed, this method will be available for the destruction of the pest before the seed is distributed and sown.

○